Dynamics of EEG Potentials at the Beginning of a Series of EEG-Feedback Sessions

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We studied changes in the amplitudes of event-related EEG potentials (ERPs) and power spectra of background EEG in the course of a series of EEG-feedback sessions directed toward an increase in the ratio of powers of the α *vs* θ rhythms. The examined group included 70 volunteers divided into an experimental group ($n = 37$) and a control group ($n = 33$). The intensity of acoustic white noise overlapping the musical background served as a feedback signal; it became lower with increase in the above ratio, while in the control group it remained constant. The EEG potentials were recorded from C3 and C4 leads. The ERPs were recorded within a paradigm of measuring time intervals. Within a series of EEG-feedback sessions, the α/θ ratio decreased somewhat both in the control and experimental groups, but in subjects of the latter group this decrease was less significant, and the mean intragroup index became significantly greater than the respective value in the control group after the end of the third session. The EEG-feedback sessions also resulted in significant increases in the amplitudes of early components of the readiness potential in both hemispheres and in the amplitude of the contingent negative variation in the right hemisphere. We conclude that, in most healthy subjects, at least three sessions of α/θ training are necessary to form an effective series providing considerable changes in the pattern of EEG potentials.

Keywords: feedback by EEG characteristics (neurofeedback), EEG frequency components, measuring of time intervals, event-related EEG potentials (ERPs).

INTRODUCTION

Recent studies demonstrated that the parameters of EEG correlate with the characteristics of the current functional state of the person, in particular with the level of his/her general activation, self-feeling, and emotional state [1-6]. Close interrelations between the corresponding electrical, neural, and psychophysiological processes form the basis for a technique of feedback by EEG characteristics (EEG-feedback, neurofeedback, neurotherapy). According to this method, a subject, using different techniques of self-regulation of his/her current psychophysiological state (physical relaxation, mental relaxation, or, *vice versa*, concentration of attention) and taking into account the feedback signal informing about one

frequency/amplitude EEG characteristic or another, tries to provide a desirable shift in the above state.

The so-called α/θ training is one of the most frequently used EEG-feedback protocols. It is aimed at an increase in the ratio of the power of the α rhythm and that of the θ rhythm. As a rule, high values of the α/θ ratio correlate with the state of relaxation of the subjects. Thus, sessions resulting in an increase in the α/θ power ratio demonstrated their efficacy in the treatment of neuroses, endogenous depression, sleep disorders, addictive disorders, and chronic fatigue syndrome; these measures also provided a decrease in the level of anxiety and eliminated psychoemotional tension (in particular that resulting from work with PCs) [7-10]. There is information that training directed toward an increase in the power of the so-called sensorimotor rhythm (close to the α activity) helps in the treatment of seizure disorders [11].

Despite the fact that α/θ trainings began to be extensively used in practice, the nature of the positive effects of EEG-feedback sessions on processes

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developing in the CNS and in the organism in general remain, to a considerable extent, unknown; only separate more or less well-based hypotheses have been proposed in this aspect. It is supposed that such trainings result in changes in the excitability of neocortical neurons with respect to ascending influences from the ventrobasal thalamic complex [11] or from the nonspecific brainstem systems [12].

Considering the above-mentioned situation, it appears expedient to examine not only changes in the EEG frequency pattern observed in the course of training and after its termination but also modifications of endogenous discrete EEG phenomena, event-related EEG potentials (ERPs). The amplitude characteristics of ERPs are to a considerable extent determined by the activity of nonspecific ascending cerebral systems and rather clearly correlate with the existing neuro- and psychophysiological state of the individual [13]. Earlier, we found that even single sessions of α/θ training result in a significant shortening of the time of the sensorimotor reaction and an increase in the amplitude of the contingent negative variation (CNV); the tests were carried out under conditions of the two-stimulus experimental paradigm with warning and imperative signals [14]. Examination of the pattern of modifications of ERPs in an experimental situation with interval measuring of preset time intervals is also of obvious interest. Such an experimental paradigm involves the subject in a rather complex activity requiring measuring of the time intervals and preparing the subject for realization of a self-initiated movement under conditions of a significant level of uncertainty [15]. There are reasons to expect that the complex of endogenous ERPs recorded in this experimental situation, which includes the readiness potential (RP), CNV, and potential P300, should undergo some modifications under the influence of a series of EEG-feedback sessions.

We should also mention that single sessions of α/θ training provide a significant increase in the ratio of powers of the α and θ rhythms only in some individuals, while in the whole group the effects appear as relative mild trends toward changes in the powers of EEG rhythms [14, 16]. Only a long series, including 10 to 15 sessions, usually results in sufficiently stable changes in the powers of EEG frequency components in most participants of the tests [8, 17]. At the same time, the dynamics of the EEG frequency pattern within the initial period of training (e.g., that including three EEG-feedback sessions) remain insufficiently studied.

This is why we tried to examine the dynamics of the pattern of background EEG within three sessions of α/θ training and to analyze changes in the amplitude parameters of ERPs recorded within the paradigm of measuring of time intervals in the course of the above training.

METHODS

Seventy healthy subjects, students of the Vernadskii Tavricheskii National University (Ukraine), men and women, 18 to 30 years old, took part in the study. Among them, 37 persons formed the experimental group, while 33 persons were included in the control group. All tested subjects were volunteers and were not in a state of emotional stress.

In members of the experimental group, we recorded ERPs (within the paradigm of measuring of the time interval) two times, before the first and after the third EEG-feedback session directed toward an increase in the α/θ spectral power ratio. In subjects of the control group, this procedure was also performed two times, before and after three sessions of listening for a presumably indifferent acoustic (musical) background. The EEG-feedback sessions and sham sessions were carried out during three successive days, one session per day, and at one and the same time of the day.

The EEG phenomena were recorded using a computerized set, including an encephalograph, a laboratory interface, and a computer. As a working software, SPECTR (developed by A. V. Sukhinin) and BFB-2 (developed by V. B. Arbatov) were used. The EEG potentials were recorded monopolarly, from C3 and C4 leads according to the 10-20 system. Combined contacts localized above the *proc. mastoidei* served as a reference electrode. Channels of the amplifier were modified in a way providing reproduction of the frequency band from 0.016 to 70 Hz.

Within the framework of the task of measuring the time interval, the tested person was asked many (about 30) times to measure subjectively a 20-sec-long interval by pushing consequently a button by the thumb of the right hand. Counting was begun by the subject by an initial (start) pushing at a voluntary chosen moment. When the subject finished measuring a correct (by his/her subjective opinion) interval, he/she had to push the button again (the finish pushing). The subject was informed that he/she will know whether the measured interval is correct or not by the presentation of a feedback signal on a light-emitting diode board. The 1-sec-long signal was switched on 2 sec after the finish pushing; it looked like a vertical

bar when the measurement was sufficiently correct (20 ± 1 sec), like a "minus" symbol when the subject measured a too short time interval (shorter than 19 sec), and like a "plus" symbol if the interval was too long (longer than 21 sec).

In the experimental situation used, several consequent endogenous ERPs were recorded. Before the finish pushing, the RP was recorded (similarly to what occurred after the start pushing); then, before the feedback signal, the CNV developed, and the P300 potential related to the perception of the significant (for the tested subject) information on the successfulness of the test performance, was recorded after the feedback signal. The mean amplitudes of the RP were measured for its early and late components (within the 1.0 to 0.5 sec and 0.5 to 0.1 sec intervals before pushing the button).

Each EEG-feedback session included three stages. Within the first stage (2.5 min long), a neutral acoustic background was presented to the subjects. They listened to calm music combined with acoustic white noise of constant intensity. Within the second stage (5 min long), the subjects were asked to try to control the ratio of the α *vs* θ spectral powers with orientation on the acoustic feedback signal. The loudness of white noise decreased with increase in the power of the α rhythm and with drop in the θ spectral power (the noise intensity dropped, and this signal could be eliminated entirely). In the opposite case, the noise intensity increased. Within the third stage (2.5 min long, an aftereffect of the session), the feedback signal was switched off, while the musical background was preserved.

Subjects of the control group were asked to listen to the same musical background with the same time characteristics as in the experimental group (2.5-, 5.0-, and 2.5-min-long stages); white noise was present within the first and second stage, but the subject was not asked to try to control the EEG parameters. The noise intensity was stable within the entire time.

According to the instruction, subjects of both groups should sit with their eyes open, trying to provide mental and physical relaxation. Subjects of the experimental group could make this purposefully, considering the feedback signal.

After testing, the EEG spectrum was analyzed using fast Fourier transformations. Normalized spectral powers of EEG oscillations were calculated for the following frequency ranges: δ (1 to 4 Hz), θ (4 to 8 Hz), α (8 to 14 Hz), and β (14 to 30 Hz). The data obtained were processed using STATISTICA software. Depending on the shape of the distributions of the indices, we used parametric or non-parametric criteria of comparison. Other details of the methods have been described earlier in our papers and also in reports of other authors who used analogous experimental paradigms and approaches [14-16].

RESULTS AND DISCUSSION

In our study, we observed changes in different neurophysiological indices under the influence of EEG feedback sessions or their imitation.

Presentation of a complex acoustic signal, a combination of white noise and musical background, to subjects of the control group resulted in the following most clear modifications of the EEG frequency pattern. The power of the α rhythm usually decreased in both hemispheres; such a drop reached a statistically significant level at the end of the sessions (Table 1, Fig. 1A). This fact can be explained as related to the development of a desynchronization reaction due to the action of an extra stimulus, i.e., the combination of white noise and musical background within the first and second stages of the session and of only musical background within the third stage. In other words, modifications of the α rhythm in the control group were to a significant extent opposite to the desirable ones. Within the first and second sessions, subjects of this group also demonstrated a significant decrease in the power of the β rhythm, but, later on, its power returned to the initial level.

In the course of the first EEG-feedback session, subjects of the experimental group showed a significant decrease in the powers of the examined EEG rhythms within the second and third stages of this session, as compared with the initial (first) session (Table 2, Fig. 1B). At the same time, we observed a trend toward an increase, from session to session, in the power at the α rhythm within the analogous session stages; it was more clearly expressed in the right hemisphere. In the course of the first stage of the first session, subjects of the above group were characterized by a somewhat lower α power in the right hemisphere as compared with that in the left hemisphere. Under the influence of EEG feedback sessions, the asymmetry of this rhythm was inverted; the power of the α component became greater in the right hemisphere. On the contrary, subjects of the control group did not show such changes in the asymmetry. The situation where a lower α rhythm power is observed in the right hemisphere, as compared with that in the left hemisphere, is usually related to a state of depression

TABLE 1. Values of the Mean Spectral Powers ($M \pm m$, μV^2/Hz) of the EEG Frequency Components in the Control Group (n = 33)

EEG rhythms	Stage 1 musical background + white noise	Stage 2 musical background + white noise	Stage 3 musical background
		session 1	
δs	7.31 ± 0.86	7.36 ± 0.85	7.61 ± 0.92
θs	6.47 ± 0.87	6.68 ± 1.02	6.27 ± 0.89
αs	16.39 ± 2.76	14.56 ± 2.64	13.59 ± 2.69*
βs	1.48 ± 0.14	1.37 ± 0.14*	1.28 ± 0.14***
δd	7.16 ± 0.82	7.18 ± 0.78	7.42 ± 0.86
θd	6.44 ± 0.91	6.54 ± 1.04	6.19 ± 0.95
αd	15.83 ± 2.67	14.05 ± 2.49	13.08 ± 2.53 *
βd	1.45 ± 0.14	1.33 ± 0.14**	1.24 ± 0.13***
		session 2	
δs	7.74 ± 0.71	7.49 ± 0.69	6.87 ± 0.63
θs	7.36 ± 1.01**	7.09 ± 1.17	6.19 ± 0.91
αs	17.79 ± 2.84	15.36 ± 2.72	13.73 ± 2.66
βs	1.68 ± 0.16	1.48 ± 0.14	1.35 ± 0.13
δd	7.44 ± 0.64	7.09 ± 0.62	6.57 ± 0.59
θd	6.89 ± 0.87	6.54 ± 0.95	5.75 ± 0.77
αd	16.63 ± 2.63	13.99 ± 2.24	12.44 ± 2.27*
βd	1.59 ± 0.14	1.39 ± 0.12	1.26 ± 0.11*
		session 3	
δs	8.37 ± 1.05	8.47 ± 1.44	7.72 ± 0.99
θs	7.34 ± 0.88	7.48 ± 1.13	6.79 ± 1.04
αs	16.49 ± 2.47	14.13 ± 2.13	11.65 ± 1.89*
βs	1.65 ± 0.17	1.51 ± 0.17	1.42 ± 0.18
δd	8.27 ± 1.06	8.41 ± 1.42	7.71 ± 1.02
θd	7.21 ± 0.88	7.26 ± 1.08	6.61 ± 1.01
αd	14.87 ± 2.22	12.78 ± 1.92	10.68 ± 1.76*
βd	1.67 ± 0.19	1.54 ± 0.19	1.45 ± 0.20

Footnotes. Indices s and d show records from the left and right hemisphere, respectively. Asterisks show values significantly different from the initial values (session 1, stage 1): *$P > 0.05$, **$P > 0.01$, and ***$P > 0.001$.

and domination of negative emotions [1, 2, 17]; thus, we can believe that changes in the interhemisphere asymmetry observed in our study reflect some trend toward an improvement of the psychoemotional state of the subjects under the influence of EEG feedback.

EEG patterns in the experimental and control groups were also dissimilar in the β rhythm dynamics. It is thought that a higher power of the β rhythm is found in persons subjected earlier to stress, and this can be accompanied by the development of various autonomic disorders [18]. In subjects of the experimental group, we observed decreases in the β rhythm power not only in the course of a separate EEG feedback session but also from session to session. This phenomenon can be related to some decrease in the strain level in these persons, as compared with subjects of the control group.

The above-described differences between normalized powers of the EEG rhythms in subjects of the control and experimental group were, as a rule, insignificant (Fig. 1). This circumstance is probably related to the limited number of sessions; because of this, the observed moderate trends were not transformed in clear shifts. Only the dynamics of the power of the δ rhythm were significantly dissimilar in the members of different groups; this power noticeably dropped in the course of α/θ training. We suppose that the attention of the subjects was attracted to a feedback acoustic signal, and this supported a definite level of general cerebral activation in these persons. The latter level demonstrated greater fluctuations in subjects of the control group, and its decrease could be accompanied by a higher power of the δ rhythm.

Because EEG feedback trainings were directed toward an increase in the α/θ power ratio, a comparison of the dynamics of these rhythms in the subjects of the two groups was most interesting. The initial value of this ratio in members of the experimental group was, on average, somewhat greater than that in the control group (Fig. 2); this difference, however, was below the

TABLE 2. Values of the Mean Spectral Powers ($M \pm m$, μV^2/Hz) of the EEG Frequency Components in the Experimental Group ($n = 37$)

EEG rhythms	Stage 1 musical background + white noise	Stage 2 orientation to a feedback signal (intensity of white noise)	Stage 3 musical background (after-effect period of the sessions)
	session 1		
δ s	7.11 ± 0.65	6.58 ± 0.51*	6.31 ± 0.53*
θ s	6.32 ± 0.63	6.05 ± 0.59	5.89 ± 0.62**
α s	15.92 ± 2.02	14.30 ± 1.82***	13.20 ± 1.68**
β s	1.81 ± 0.20	1.73 ± 0.19*	1.65 ± 0.19***
δ d	7.21 ± 0.69	6.78 ± 0.59	6.38 ± 0.58*
θ d	6.54 ± 0.75	6.27 ± 0.69	5.93 ± 0.63**
α d	15.57 ± 1.79	14.01 ± 1.68**	12.68 ± 1.45***
β d	1.83 ± 0.18	1.73 ± 0.18**	1.65 ± 0.17***
	session 2		
δ s	6.05 ± 0.69	5.79 ± 0.58	5.83 ± 0.64
θ s	6.36 ± 0.89	5.71 ± 0.69	5.37 ± 0.64**
α s	15.93 ± 2.65	14.38 ± 2.36	13.32 ± 2.04
β s	1.54 ± 0.19	1.43 ± 0.18**	1.45 ± 0.18*
δ d	5.99 ± 0.71	5.92 ± 0.64	5.99 ± 0.72
θ d	6.15 ± 0.82	5.79 ± 0.71	5.57 ± 0.72
α d	16.15 ± 2.74	14.92 ± 2.49	13.94 ± 2.19
β d	1.51 ± 0.19	1.41 ± 0.18**	1.44 ± 0.17***
	session 3		
δ s	6.52 ± 0.85	5.99 ± 0.69	6.53 ± 1.04
θ s	6.77 ± 1.17	5.98 ± 0.88	5.65 ± 0.87
α s	17.05 ± 2.76	14.61 ± 2.29	13.14 ± 2.32
β s	1.42 ± 0.22*	1.29 ± 0.19**	1.25 ± 0.20***
δ d	6.45 ± 0.83	5.96 ± 0.78	5.62 ± 0.50*
θ d	6.74 ± 1.04	5.92 ± 0.76	5.38 ± 0.67
α d	17.86 ± 2.95	15.51 ± 2.46	13.49 ± 2.21
β d	1.42 ± 0.21*	1.32 ± 0.19**	1.26 ± 0.19***

Footnote. Designations are similar to those in Table 1.

level of significance. It seems probable that this fact is related to a definite emotional tuning and a greater concentration of attention in tested subjects of the experimental group who checked for the beginning of an EEG feedback session. In the course of all the three sessions, the ratio of the powers of the α and θ rhythms in both hemispheres, in general, decreased in both the control and experimental groups, i.e., the effect after three sessions in the experimental group was opposite to the expected one. The decrease in this ratio in the members of the experimental group was, however, noticeably less considerable than that in the subjects of the control group. Intergroup differences between the α/θ ratios were greater in the right hemisphere. The above ratio at the end of the third session in subjects of the experimental group not only reached values greater than those in the left hemisphere but also significantly exceeded this index in the right hemisphere of subjects of the control group. It is obvious that the observed intergroup dissimilarities

between values of the above index could be related exclusively to targeted attempts of members of the experimental group to raise this ratio and, in a parallel manner, to decrease the psychoemotional strain and to provide motor and mental relaxation.

Thus, in summarizing the results of analysis of the dynamics of the pattern of background EEG activity within the initial stage of the series of EEG feedback α/θ training sessions, we can conclude that three such sessions are sufficient to provide significant shifts in the EEG spectral pattern; this effect, first of all, is manifested in a relative (as compared with the control group) increase in the ratio of powers of the α and θ rhythms. These modifications are manifested despite their significant masking by considerable shifts in the EEG activity in both groups under the influence of complex acoustic signals and also by large interindividual specificities of the EEG pattern in different participants of the study. Our results agree with the earlier conclusions on the insufficiency of
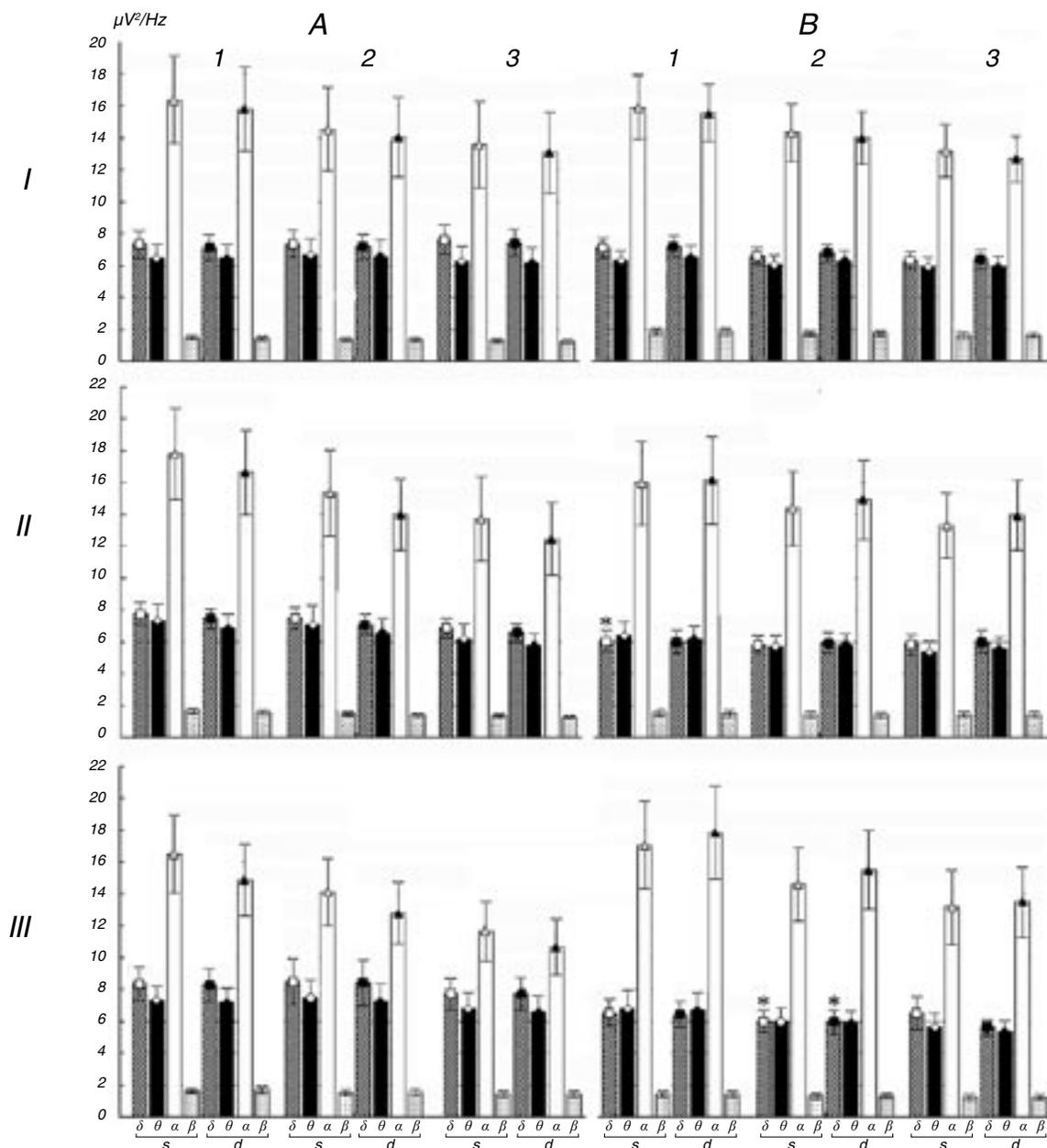
Fig. 1. Spectral power (μV²/Hz) of δ, θ, α, and β EEG rhythms recorded from central leads of the left (*s*) and right (*d*) hemispheres of tested subjects in the course of the control series (A) and of three EEG feedback sessions (B). I-III are three successive sessions or their imitations; each session included three stages, 1-3 (see the text). Means ± s.e.m. are shown; asterisks show cases of significant (*P* < 0.05) differences from values in the control group.

single EEG feedback sessions that cannot provide significant modifications of the background EEG pattern [14, 16]. We suppose that an effective series of α/θ trainings should include, for most healthy subjects, at least three sessions.

Under conditions of measuring the time intervals, all cases of performance of this test could be classified in three unequal groups. These were fits with the preset interval (19 to 21 sec), pushings of the button before the right moment (earlier than 19 sec), and delayed pushings (later than 21 sec). Within the aftereffect periods of both EEG feedback sessions and their initiations, the quantitative relations between reactions of the above types changed. This effect was manifested in an increase in the number of successive fits (Fig. 3). This figure shows that such shifts were observed in members of both experimental and control groups. It is obvious that realizations of the
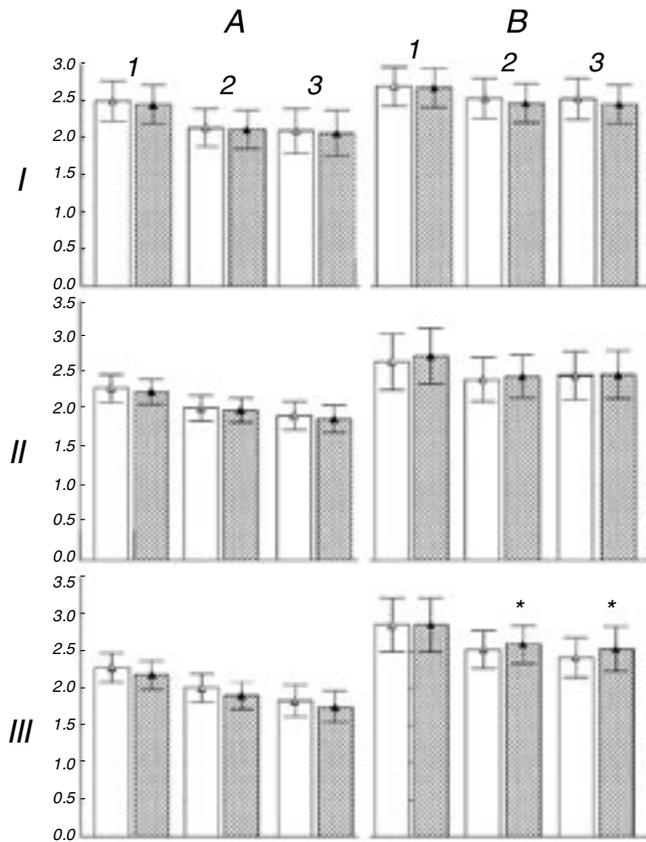
Fig. 2. Ratios of spectral powers of the α and θ EEG rhythms recorded from central leads within the control series (A) and upon carrying out three EEG feedback sessions (B). Open and dashed columns show values for the left and right hemispheres, respectively. Other designations are similar to those in Fig. 1.
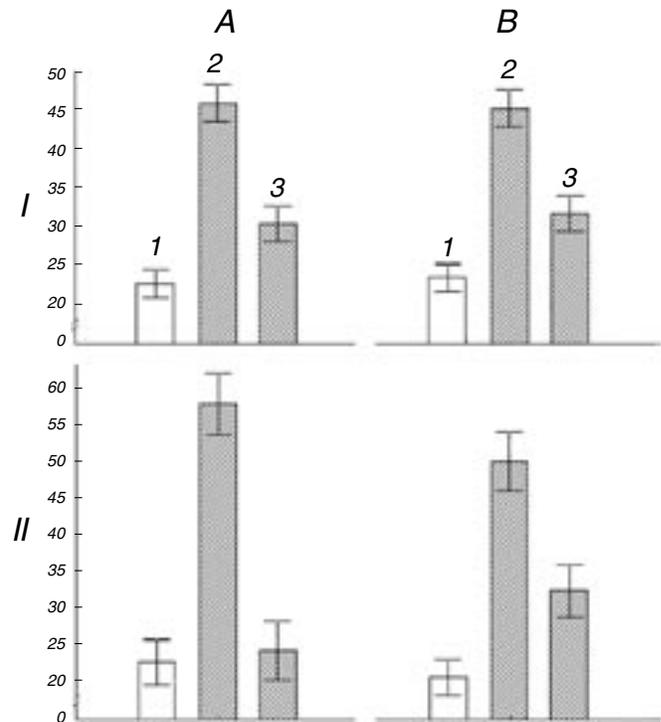

Fig. 3. Quantitative relations (%) between values of the time intervals measured by subjects of the control (A) and experimental (B) groups before (I) and after (II) three EEG feedback sessions or their imitations. 1-3 are intervals shorter than (<19 sec), corresponding to (successful, 19 to 21 sec), and longer than (>21 sec) preset values. Other designations are similar to those in Fig. 1.

task improved at repeated performances due to the process of learning. Such improvement, however, was manifested in the experimental group to a lesser extent than in the control group. This finding appeared somewhat surprising for us because earlier we noted that indices of the sensorimotor reactions improved within the aftereffect period of α/θ training [14]. We can assume that the state of relaxation attained by the subjects in the course of EEG feedback sessions helped in the performance of relatively simple tasks (realization of a simple sensorimotor reaction) but exerted no positive influence on the performance of a more complex task, namely internal measuring of time intervals. Due to intensification of the relaxation state within the aftereffect period of EEG feedback sessions, the subjects probably tended to measure a longer time interval and delayed pushing the button. In this case, however, we observed a negative correlation between the value of the ratio of the α and θ rhythms

in the left hemisphere of subjects of the experimental group observed within the final stage of the third EEG feedback session and the duration of the time interval measured under these conditions ($r = -0.41$ at $P = 0.01$). There was also a rather clearly expressed trend toward a positive correlation of the above ratio of the rhythm powers and the number of fits with the preset interval ($r = 0.30$ at $P = 0.07$). In other words, those members of the experimental group who attained not only a state of relaxation but also a high ratio of α and θ spectral powers provided a higher-quality performance of the measuring task; they demonstrated a smaller number of cases of delayed motor reaction (pushing the button), as compared with other members of their group.

Subjects of the control group showed no significant changes in the amplitudes of ERPs within the aftereffect period of imitations of EEG feedback sessions. The averaged amplitude of an early component of the RP
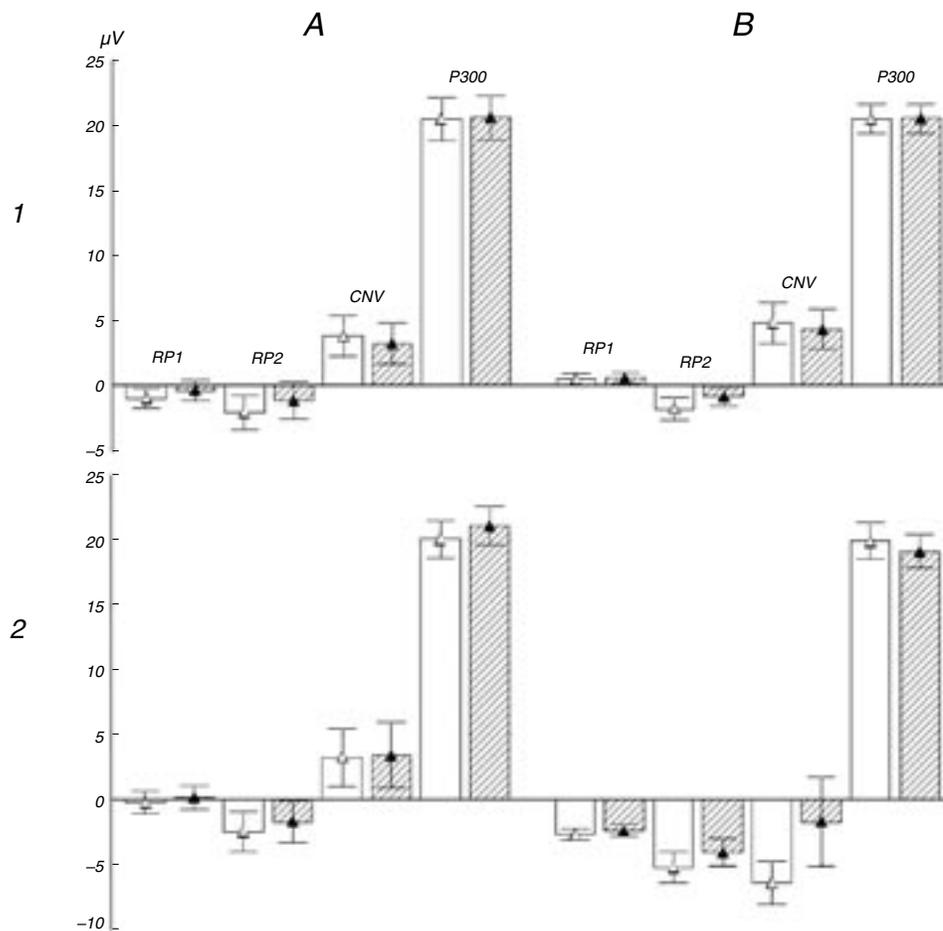
Fig. 4. Amplitudes of the early and late components of the readiness potential (RP1 and RP2, respectively), of the contingent negative variation (CNV), and of the P300 wave recorded from central leads before (1) and after (2) the control series (A) and upon carrying out three EEG feedback sessions (B).

(RP1) decreased somewhat (Fig. 4). At the same time, the amplitude of both components of the RP increased considerably within the aftereffect periods of EEG feedback sessions. The rise in the RP1 amplitude, as compared with this parameter in the control group, was significant in both hemispheres. As is believed, the early part of the RP is mostly generated by neuronal networks of the accessory motor cortex, while the late phase is produced by networks of the primary motor cortex [19]. The fact that EEG feedback sessions provided mostly an increase in the RP1 amplitude can indicate that the excitation/inhibition balance improves just in the accessory motor region.

The mean amplitude of the CNV increased in both hemispheres only in subjects of the experimental group, and intergroup differences between the means of the CNV amplitudes reached the significance level. Generation of the CNV is known to be tightly

related to such mental processes as expectation for a relevant signal and intensification of attention [13]. Within the framework of our experimental paradigm, the CNV should, in fact, be considered the so-called prestimulus negativation [20] because this potential developed within a period corresponding, in the mental aspect, to waiting for a feedback signal informing on the success/failure in the performance of the time counting. It can be supposed that a rise in the CNV amplitude is indicative of the development of some central processes assisting in the resolution of a complex cognitive task despite the formed state of psychophysiological relaxation.

The amplitude of the P300 potential changed only insignificantly under conditions of our tests in the subjects of both the experimental and control groups.

Thus, at least such ERPs as the RP and CNV changed significantly within the aftereffect period

of α/θ training. This is why we analyzed correlations between the amplitudes of ERP components and the value of the α/θ rhythm ratio reached after the third session in members of the experimental group. The amplitude of the RP late component (RP2) in the left hemisphere correlated significantly with the ratio of the powers of the above rhythms in the right hemisphere ($r = 0.39$ at $P = 0.03$). The CNV amplitude in the left hemisphere correlated in a similar manner with the ratio of α/θ rhythm powers in both hemispheres ($r = 0.37$ at $P = 0.04$). The amplitude of the P300 potential also correlated positively and highly significantly ($P = 0.01$) with the above power ratios in the left and right hemispheres ($r = 0.50$ and 0.47, respectively), while the P300 amplitude in the right hemisphere correlated positively with the ratios of the above rhythms in the left and right hemispheres ($r = 0.48$ at $P = 0.01$ and $r = 0.43$ at $P = 0.02$, respectively). Thus, the greater the attained ratio of the spectral powers of the α and θ rhythms in the course of EEG feedback training, the higher the amplitudes of ERPs observed in subjects of the experimental group in the process of performance of the time measuring. This dependence reflects the following well-known fact: There are positive correlations of the amplitudes of the RP, CNV, and P300 with the level of manifestation of the α rhythm and and the ratios of the power of this rhythm with the powers of other rhythms [21].

The data obtained allow us to propose some hypotheses on the mechanisms underlying the EEG feedback effects. The amplitudes of different ERP components are known to be determined, in general, by cerebral mechanisms regulating the excitability of the neocortex [13]. The surface negativity or positivity in the neocortex reflects, correspondingly, a drop or a rise in the excitability of cortical pyramidal neurons related, to a great extent, to the respective changes in the membrane potential of the apical dendrites of these cells. It is believed that circulation of excitation via neuronal circuits of the neocortex – striatum – thalamic reticular nucleus – thalamic medial nonspecific nuclei – apical dendrites of cortical neurons represent one of the most important processes in the brain. These circuits are under the control of aminergic neuromodulatory systems. Therefore, increases in the ERP amplitudes observed within the aftereffect periods of EEG feedback sessions in our study can, to a great extent, result from changes in the neuronal excitability related to transformations of the influences exerted by aminergic brainstem systems on the above-mentioned cortical-subcortical circuits. Experiments with simultaneous recording of impulse activity of aminergic brainstem

neurons and EEG activity carried out in our laboratory on awake animals (cats) supported the above supposition [22]. Correlation analysis demonstrated the existence of a close positive resemblance between the frequencies of background spike activity of most adrenergic neurons localized within the *locus coeruleus* region and serotonergic neurons in the *raphe nuclei*, on the one hand, and powers of the main EEG rhythms, on the other hand.

It seems logical to suppose that changes in the functional state of a person in the course of EEG feedback training, which is directed toward a decrease in the psychoemotional strain and motor/mental relaxation, develop in close correlation with transformations of the activity of the brainstem aminergic systems and shifts in the EEG frequency pattern. Thus, the results of our study can be considered proofs supporting the hypothesis that effects of such trainings result from rearrangement of the effects of nonspecific aminergic systems of the brainstem on neurons of the cerebral mechanisms controlling the level of excitability of the neocortex [12].

REFERENCES

1. I. G. Kalashnikova, "Individual/typological peculiarities of EEG correlates of emotional reactions in humans," *Sechenov Fiziol. Zh.*, **81**, No. 10, 108-112 (1995).
2. M. B. Kostyunina and M. A. Kulikov, "Emotion-related frequency characteristics of EEG spectra," *Zh. Vyssh. Nerv. Deyat.*, **45**, No. 3, 453-457 (1995).
3. H. J. Crawford, S. W. Clarke, and M. Kitner-Triolo, "Self-generated happy and sad emotions in low and highly hypnotizable persons during waking and hypnosis: laterality and regional EEG activity differences," *Int. J. Psychophysiol.*, **24**, No. 3, 239-266 (1996).
4. M. B. Kostyunina, "Electroencephalogram related to mental image of emotionally colored events in humans," *Zh. Vyssh. Nerv. Deyat.*, **48**, No. 2, 213-221 (1998).
5. C. M. Krause, V. Viemero, A. Rosenqvist, et al., "Relative electroencephalographic desynchronization and synchronization in humans to emotional film content: an analysis of the 4-6, 6-8, 8-10 and 10-12 Hz frequency bands," *Neurosci. Lett.*, **286**, No. 1, 1-4 (2000).
6. L. I. Aftanas, N. V. Reva, A. A. Varlamov, et al., "Analysis of evoked EEG synchronization and desynchronization in conditions of emotional activation in humans: temporal and topographic characteristics," *Neurosci. Behav. Physiol.*, **34**, No. 8, 859-867 (2004).
7. K. Rice, E. Blanchard, and M Purcell, "Biofeedback treatments of generalized anxiety disorder: preliminary results," *Biofeedback Self-Regul.*, **18**, No. 2, 93-105 (1993).
8. S. I. Soroko and T. Zh. Musuraliev, "Possibilities for targeted rearrangements of EEG parameters in humans

using the technique of adaptive biocontrol," *Fiziol. Cheloveka*, **21**, No. 5, 5-17 (1995).

9. D. C. Hammond, "Treatment of chronic fatigue syndrome with neurofeedback and self-hypnosis: a case report," *J. Neurother. (http:www.isnr.org)*, **3**, No. 4, (1999).

10. V. L. Tyunin and V. B. Pavlenko, "Correlation of negative effects of intensive work with a computer using electroencephalographic feedback," *Problems, Achievements, and Prospects of Development of Med. Biol. Sciences and Pract. Healthcare*, **140**, No. 3, 174-178 (2004).

11. B. Sterman, "Physiological origins and functional correlates of EEG rhythmic activities: implication for self-regulation," *Biofeedback Self-Regul.*, **21**, No. 1, 3-33 (1996).

12. J. F. Lubar, "Neocortical dynamics: implication for understanding the role of neurofeedback and related techniques for the enhancement of attention," *Appl. Psychophysiol. Biofeedback*, **22**, No. 2, 111-126 (1997).

13. N. Birbaumer, T. Elbert, A. Canavan, and B. Rocstron, "Slow potentials of the cerebral cortex and behavior," *Physiol. Rev.*, **70**, No. 1, 1-41 (1990).

14. V. B. Pavlenko, I. N. Konareva, E. S. Shutova, and S. V. Chernyi, "Use of electroencephalographic biofeedback for correction of the psychophysiological state of humans," *Tavrichesk. Med.-Biol. Vestn.*, **4**, No. 4, 56-60 (2001).

15. V. B. Pavlenko and I. N. Konareva, "Individual personality-related characteristics of event-related EEG potentials recorded in an experimental situation requiring production

of time intervals," *Neurophysiology*, **32**, Nos. 1, 38-44 (2000).

16. I. N. Konareva, "Modifications of the EEG frequency pattern in humans related to a single neurofeedback session," *Neurophysiology*, **37**, Nos. 5/6, 388-395 (2005).

17. D. C. Hammond, "Neurofeedback with anxiety and affective disorders," *Child Adolesc. Psychiat. Clin. North Am.*, **14**, No. 1, 105-123 (2005).

18. E. A. Zhirmunskaya, *Functional Interrelations between Brain Hemispheres in Humans: Statistical Analysis of Electroencephalograms in Cerebral Insult* [in Russian], Nauka, Moscow (1989).

19. R. Q. Cui and L. Deecke, "High resolution DC-EEG analysis of the Bereitschaftpotential and post movement onset potentials accompanying uni- or bilateral voluntary finger movements," *Brain Topogr.*, **11**, No. 3, 233-249 (1999).

20. E. J. P. Damen and C. H. M. Brunia, "Changes in heart rate and slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task," *Psychophysiology*, **24**, No. 6, 700-713 (1987).

21. I. N. Konareva and V. B. Pavlenko, "Interrelations between rhythmic activity of the cerebral cortex, evoked potentials, and characteristics of the personality," *Uchen. Zap. Tavrichesk. Nats. Univ.*, **14 (53)**, No. 3, 11-15 (2001).

22. O. I. Kolotilova, A. M. Kulichenko, Yu. O. Fokina, et al., "Effect of brainstem structures on the pattern of mass electrical activity of awake cats," *Uchen. Zap. Tavrichesk. Nats. Univ.*, **18 (57)**, No. 2, 34-42 (2005).